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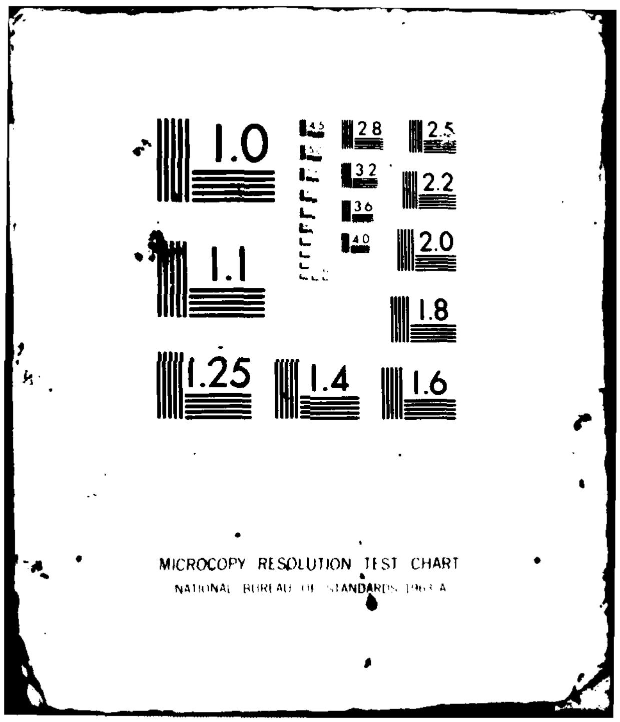
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HEC ACTIVITIES IN RESERVOIR ANALYSIS

by

VERNON R. BONNER

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HEC ACTIVITIES IN RESERVOIR ANALYSIS[1]

by

Vernon R. Bonner[2]

INTRODUCTION

Over the last 15 years, The Hydrologic Engineering Center (HEC) has been developing, applying, and distributing computer programs dealing with various aspects of hydrologic engineering, including reservoir analysis. The Center has developed several models for the simulation of reservoir operation and has supported the development of a water quality model for reservoirs and rivers. This paper presents a review of model development and an overview of the capabilities and types of applications for the most recent computer programs, "Simulation of Flood Control and Conservation Systems" (HEC-5) and "Water Quality for River-Reservoir Systems" (WQRRS). Also, current research and development dealing with reservoir analysis are described.

PROGRAM DEVELOPMENT

The Hydrologic Engineering Center has been involved with the development, distribution and support of computer programs since its inception in 1964. Early programs were small, single-purpose routines like Gate Regulation Curve (1), Spillway Rating and Flood Routing (2), and Reservoir Yield (3). All three programs were released in 1966.

During the mid-sixties, the computer program, "Reservoir System Analysis for Conservation" (HEC-3) (4) was developed by Leo R. Beard. Program capabilities were expanded and by 1974, the fourth generation model was released with a full range of capabilities to simulate a reservoir system for typical conservation objectives of minimum flows, diversions and hydropower generation. During the early seventies, the HEC-3 program was applied to a number of reservoir studies at the Center. (5,6,7). The program is still actively used and at last count, 200 source decks had been distributed.

Although the HEC-3 program was adequate for conservation studies, there was a need for flood control simulation within the Corps. During the early seventies, Bill S. Eichert developed a model for flood control simulation which was released in 1973 as HEC-5, "Reservoir System

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[1]Presented at the Symposium on Surface-Water Impoundments; June 2, 1980, Minneapolis, Minnesota.

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Operation for Flood Control." (8) After its release, Mr. Eichert continued to develop the model, adding conservation capabilities that were available within HEC-3. By 1975, a new version labeled HEC-5C was released with both flood control and conservation simulation capabilities. The HEC-5C label was carried by the program until a new release was made in June 1979. Now, HEC-5, "Simulation of Flood Control and Conservation Systems," (9) is our primary reservoir simulation program. Since its June release, 59 copies of the new program have been distributed. Prior to that date, there were 124 copies of earlier versions released.

Program development in the water quality area centered on reservoir temperature models during the sixties. In 1969, the Center released a monthly reservoir temperature stratification model (10) that simulates temperature variations between horizontal strata within a reservoir. During the early seventies, the need for more comprehensive quality analysis led to the development and application of several mathematical computer models. (11) The Center has adopted the ecological model of Drs. Chen and Orlob and has supported the expansion of that model with a river ecological model, developed by Mr. William Norton. Other modifications were made, and in 1974 the Center released the program, "Water Quality for River-Reservoir Systems." (WQRRS) (12) The model was capable of analyzing 18 different physical, chemical and biological water quality parameters.

In 1975, the streamflow routing capability was added to WQRRS, and in 1976 the capability to analyze branched and loop stream systems was added. The current model was created in 1978 when the preprocessors were integrated into the individual modules of the program. Today the program is distributed as three separate but integrable modules: the reservoir module, the stream hydraulics module, and the stream quality module. The stream quality module has no hydraulic computation capability and requires the hydraulic data file generated by the hydraulics module.

PROGRAM CAPABILITIES AND APPLICATIONS

The early studies with HEC-5 were generally flood control planning studies. The program flood control operation is based on maintaining nondamaging discharges at designated downstream locations while observing constraints on outlet capacity, rate of change on releases, and limits on the future foresight of inflow and inflow accuracy. Economic routines provide flood damage estimates for individual floods or expected annual damages based on multiple flood analysis. The expected value of damages is used as a basis for evaluating alternative flood control plans. (13,14,15)

More recently, the conservation capabilities of HEC-5 are being applied to reservoir yield determination problems. The program can simulate reservoir operations for minimum flow requirements, diversions, and hydropower. Hydropower operation can be for individual sites or system power requirements, and pump storage operation can also be simulated. Table 1 lists the systems simulated with HEC-5 in which the Center has had a major role.

TABLE 1

SYSTEMS SIMULATED BY HEC-5

River Basin	Location	Number Reservoirs	Number Control Points (including res)	Time Increment (hrs)
Trinity	Texas	15	28	24
Merrimack	New England	5	11	3
Susquehanna	Pennsylvania	34	75	4
Schuylkill	Pennsylvania	12	26	3
Potomac	VA,MD,PA	26	39	2
Red River-North	Minnesota	13	29	24 & 720
Feather	California	3	4	2
Pajaro	California	3	6	1 & 720
Grand (Neosho)	Oklahoma	24	86	2
James	Virginia	22	35	6
Red River	Texas,Arkansas	14	28	6
Hudson	N.Y.,PA	3	5	720
Morova	Yugoslavia	7	14	4
Little River	Oklahoma	4	9	6 & 720
Marshall Fork	Texas	1	2	24
Catskill Aqueduct	Hudson River	2	5	720
Sacramento River	California	11	16	2
Shasta-Red Bluff	California	2	5	2
Roaring Fork	Colorado	1	4	24
San Joaquin	California	22	56	6
Salt River Basin	Arizona	7	12	2 & 720
Savannah Pumped Storage	Georgia	3	5	1 & 24
White River Pumped Storage	Arkansas	3	4	1 & 24 & 720

A recent operation study (16) analyzed the impact of pump-back operation on hydropower production and recreation usability of a reservoir system on the Savannah River. The total energy requirements were specified for the three tandem reservoir system and the program allocated the energy requirements to the individual projects based on balancing the reservoir storage levels. The system allocation routine also accounts for the pump-back water and the downstream minimum flow requirements.

The need for a water quality evaluation of existing and proposed project conditions on the Trinity River in Texas required the analysis of both reservoir and stream channel conditions. These requirements led to linking of the water quality models described earlier. Existing and project conditions have also been simulated for or by other Corps offices at the proposed Tocks Island Lake, Lake Koocanusa (Libby Dam), and Lincoln Lake using variations of the Chen-Orlob model. (11)

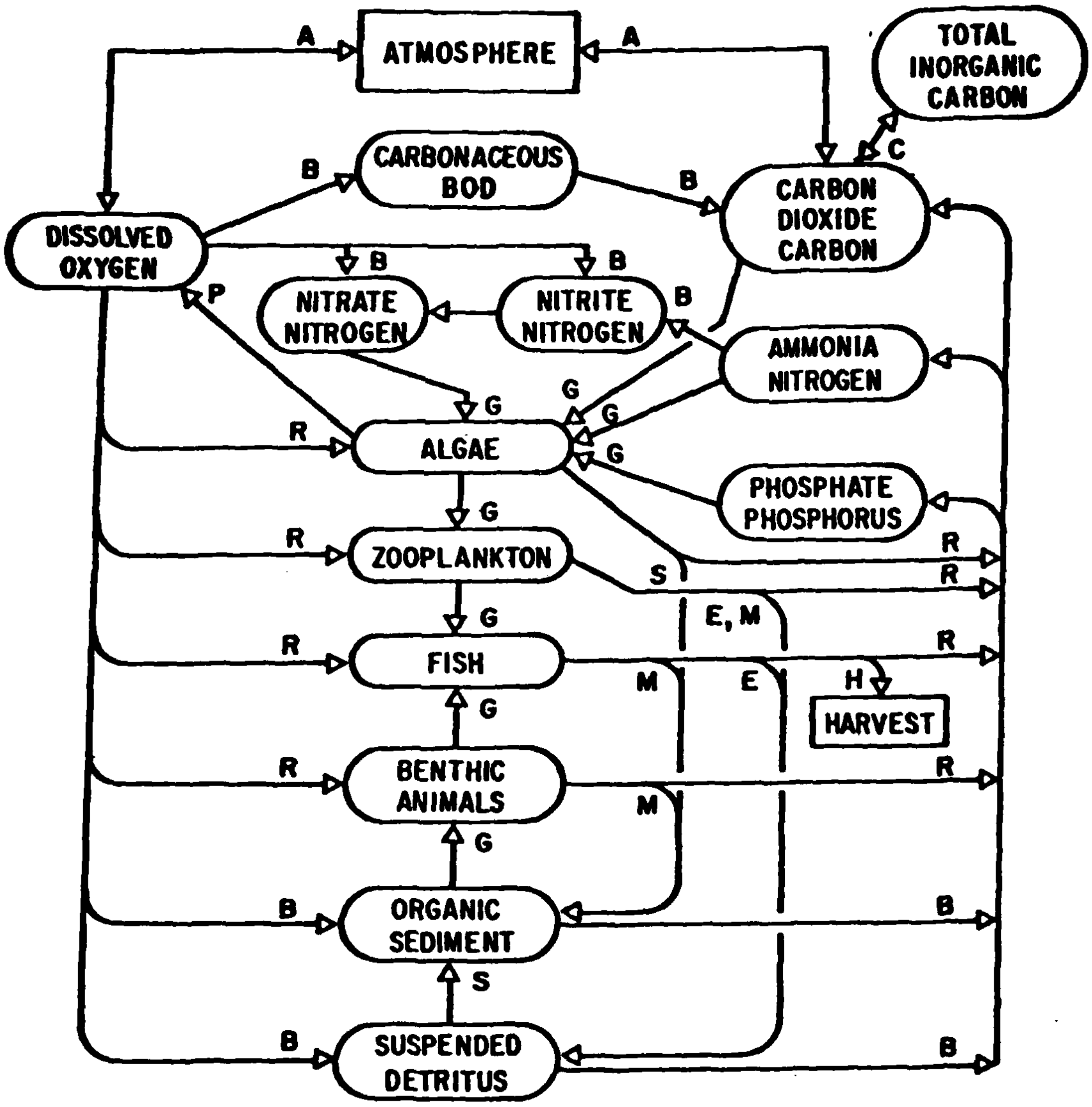
The WQRRS model reflects an attempt by HEC to provide a generalized river-reservoir water quality model which is continuously updated and maintained with the best available concepts. The reservoir module of the program is applicable to aerobic impoundments that can be represented as one-dimensional systems having horizontal isotherms. This approximation is generally satisfactory in medium to moderately large lakes or reservoirs with long residence times. The approximation may be less satisfactory in shallow impoundments or those having a rapid flow-through time. Systems that have a rapid flow-through time are often fully mixed and can be treated as slowly moving streams using the stream quality module. The reservoir model is designed to provide a detailed portrayal of the important processes that determine the thermal and water quality characteristics of lakes and reservoirs. The interdependence of constituents is shown in Figure 1.

The stream hydraulic module provides six hydraulic computation options. They are 1) steady gradually varied flow (backwater), 2) solution to the full St. Venant equations, 3) stage-flow relationship, 4) kinematic wave, 5) Muskingum, and 6) modified Puls.

In the stream quality module, the rate of transport of quality parameters can be represented for aerobic streams. Peak pollutant loads can be routed through steady or unsteady flow conditions using the routing from the stream hydraulic module. If a steady state stream water quality analysis is desired, it can be simulated by holding inputs constant for a few computation periods. Field verification of the river water quality module is currently underway for the Allegheny River.

CURRENT ACTIVITIES

Current reservoir system activities are in three functional areas: hydropower, real-time flood operations, and water quality analysis. The hydropower activity is supported by Corps Research and Development funds as well as by the Department of Energy and the Corps National Hydropower Study.



A Aeration
B Bacterial Decay
C Chemical Equilibrium
E Excreta
G Growth
M Mortality
P Photosynthesis
R Respiration
S Settling
H Harvest

Figure 1. QUALITY AND ECOLOGIC RELATIONSHIPS

An extensive data file system has been developed by the Center for use in the inventory of some 7,000 dams as a part of the National Hydroelectric Power Study. Computer software has also been written to develop HEC-5 input data automatically from the file system. With the developed software, a global request or specific site request can be made to automatically generate HEC-5 input and operate the model to determine dependable capacity, firm annual energy and average annual energy for any storage project in the files. The results are automatically returned to the files and used for economic analysis.

The HEC-5 program is also being used to determine the potential gains from reallocation of flood control storage. Using the program's yield optimization feature, the potential gain in firm and average annual energy is being determined for all existing power projects with significant flood control storage. The program's flood damage routines will provide estimates of the potential cost from loss of flood control storage.

The real-time operation work has focused on flood flow forecasts, improved linkage between forecast model and operation model, and improved interaction between the operation model and the program user. The concept of linking a forecast model with HEC-5 and providing convenient interactive output displays of operation results was demonstrated in 1975 for the Merrimack River Basin. (17) Subsequent software development has provided a new interactive output display package that provides both graphical and tabular displays of simulation results. Included in the package is the capability to create and store menus that can be utilized for input/output requests to the program and an automatic procedure to graphically input hydrographs to the model. The input hydrographs can be forecasted inflows or proposed reservoir release schedules. With the new output routines, it is possible to quickly simulate and display the program's flood operation. The operator can display results, make decisions, and reoperate the model with the new input (e.g., release schedule). The package was demonstrated at the National Workshop on Reservoir System Operations at Boulder, Colorado in August 1979. (18)

Through the Los Angeles District of the Corps of Engineers, the Salt River Project (SRP) of Phoenix, Arizona, heard about the new capabilities and requested assistance in applying the operation model to their system. Earlier planning studies had been performed using HEC-5; therefore, it was easy to develop the data files for a "real-time" operation. In mid-December 1979, a three-day training/work session was provided at the Center to demonstrate how the Salt River System could be modeled and analyzed. The Project staff made arrangements with the National Weather Service to obtain the necessary inflow forecasts. They also contracted with the computer service company where the software was developed so there would be no difficulty in transferring the data files and programs. By January they were operational and began testing the software.

The January-February flood season was a major test for project operations and the computer programs. Mr. Thomas Sands, Senior Engineer with SRP, feels the program has become an important tool during times

of critical reservoir operations. As reported in the March 20, 1980 edition of PULSE,* a record 35 computer simulations were made during the storms of February 13 and 22, 1980. The simulations were made not only to assist in reservoir release decisions, but also to provide downstream flow predictions for the bridges in Phoenix. SRP reports the program has extended their ability to analyze the effects of potential storms.

The water quality calculations are being incorporated into the reservoir simulation model HEC-5. The objective is to provide a computer program and methodology for total water management capability for complex systems of reservoirs. The model will evaluate flood control, hydropower, water quality and other project purposes and determine the "best" system regulation to meet all downstream water needs. The resultant model will also provide the first step toward a long-term water quality regulation for large multiple-purpose reservoir systems.

The first phase, completed last year, linked water temperature algorithms to HEC-5. The model, called HEC-5Q, was applied to a single reservoir operation. The second phase is now expanding the model to simulate additional water quality parameters and operate with two parallel reservoirs and two tandem reservoirs. The contract also requires solving a test case and providing appropriate documentation. Next year, the third phase will provide the capability of simulating a comprehensive reservoir system. Example operations and appropriate documentation will also be required. If it appears feasible, the model will be modified to include real-time regulation capability.

CONCLUSIONS

The need for comprehensive models to analyze reservoir-river systems is evident. The program capabilities, wide distribution, and support of HEC-5 and WQRRS make them attractive tools for the analysis of reservoir systems. Past applications of the models to a variety of problems show their worth for planning studies. With the current model development, they may also be useful tools for application to operation problems on a "real-time" basis.

*PULSE is a weekly public affairs newsletter published by the Salt River Project.

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